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Environmental Sensor Technologies and Procedures for Detecting and Identifying Indoor Air Pollution

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Public concern about environmental quality now encompasses the indoor environment–the buildings where people work and live. In recent years researchers have been discovering new links between indoor air quality (IAQ) and the occupants' comfort, health, and productivity. As the operator of many thousands of buildings, and the employer of the millions of people who use those buildings, the U.S. Army has a strong interest in maintaining and promoting good IAQ.

This report presents a concise summary of the key IAQ parameters of interest to building managers, the most common indoor air contaminants, the variety of sensor technology currently available for detecting and identifying those contaminants, and basic procedures for using that technology.

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FOREWORD

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COL Daniel Waldo, Jr., is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

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ENVIRONMENTAL SENSOR TECHNOLOGIES AND PROCEDURES FOR DETECTING AND IDENTIFYING INDOOR AIR POLLUTION

1 INTRODUCTION

Background

In recent years public concern about environmental quality has begun extending to include the indoor environment–the buildings where people work and live. The importance of indoor air quality (IAQ) is increasingly recognized by building owners and occupants alike. Every year researchers discover new connections between IAQ and the occupants' comfort, health, and productivity, whether in the workplace or at home. Indoor air pollution (IAP) can take a variety of forms. It may be something annoying, but relatively harmless, such as an unpleasant odor. It may also be something odorless–but extremely hazardous–such as carbon monoxide or radon.

Environmental sensors can help detect and identify a number of important IAQ problems that are not otherwise readily apparent. Many sensors capable of detecting an IAQ problem are operable by building managers with no special training, and can be run as part of a routine maintenance check. Managers can use such sensors to identify IAP and adjust maintenance procedures as necessary to correct the problem. These sensors can also detect problems that are beyond the control of a building manager, alerting him or her to call in professional specialists to address these problems before they threaten building occupants.

The U.S. Army operates and maintains thousands of buildings on installations throughout every part of the nation as well as overseas. Millions of people, both military and civilian, live and work in these buildings. Since the Army's mission effectiveness is directly related to the health, wellbeing, and productivity of its soldiers and civilian employees, the Army has a strong interest maintaining and promoting good IAQ within the buildings it operates. In support of the Army's efforts to promote good IAQ in its facilities, the U.S. Army Construction Engineering Research Laboratory (USACERL) has compiled this interim report to transfer fundamental information about environmental sensor technologies and procedures to building managers in the field.

Objective

The objective of this phase of the research is to provide for Army building managers and maintenance personnel a timely, concise discussion of the key IAQ parameters, the most common indoor air contaminants, the variety of sensor technology currently available for detecting and identifying those contaminants, and basic procedures for using that technology.

The overall objective of this research is to provide detailed procedures for testing IAQ parameters, interpreting findings, and addressing specific IAQ problems. The work will also include the evaluation of specific sensor technologies and guidance on their applicability to Army facilities.

Approach

This report defines two steps in the process of protecting and enhancing IAQ: first, the measuring of IAP indicators to detect the presence of a general IAQ problem; second, the measuring for specific indoor air contaminants in order to locate the cause of the specific problem. The authors reviewed current IAQ literature to identify the most common IAQ testing methods now available, including what to measure and why. Six IAP indicators, including occupant complaints, were identified as parameters to measure when determining if there is an IAQ problem. Additionally, eight contaminants were identified as the most common causes of IAQ problems. The authors provide basic procedural guidance for using sensor technology and other resources to measure the indicators listed and identify specific contaminants.

Scope

This interim report focuses on the most common IAQ problems and readily available sensor technologies that can detect them. Some IAQ problems of potential concern may not be addressed here if their occurrence is rare. Additionally, new and innovative technologies are not discussed in this report if they were not considered practical and readily available.

Although IAQ is a concern both in the workplace and in living quarters, this report focuses on IAQ in the workplace.

Mode of Technology Transfer

This information may impact Army Regulation (AR) 200-1, *Environmental Protection and Enhancement*. It may also be incorporated into a Facilities Engineering Technical Note or an updated edition of an IAQ technology transfer brochure published by USACERL. Additionally, this information may be used in the development of a USACERL workshop on diagnosing and mitigating IAP.

2 IAP INDICATORS AND COMMON CONTAMINANTS

The proper management of IAQ requires two general steps: measurement of key IAP indicators and testing to identify any specific contaminants detected. These two steps should be integrated into the job routines of building maintenance personnel. A number of testing procedures and sensing technologies can be used by maintenance personnel with no special training or education. However, some procedures and technologies will require the assistance of a trained air quality professional.

Six Key IAP Indicators

Table 1 lists six key IAP indicators, including occupant complaints, representing the main parameters that should be measured when trying to detect an IAQ problem. Although they are not an environmental indicator in exactly the same sense as the other five parameters, occupant complaints are included here because they are often the first indication of an IAQ problem. The bold listings in the "Measuring Tools" column of Table 1 represent the authors' recommended sensing technology for the given parameter, based on effectiveness and cost.

Each key indicator, and the preferred technology for measuring it, is discussed below. A glossary of all sensing technologies listed in Table 1 (and elsewhere in this report) can be found in the Appendix.

Occupant Complaints

The occupants of the building often give the first indication of an IAQ problem. Individuals may complain about discomforts they experience in the building during the work day, or may report that they remain ill even after leaving the building for a few days. Individual complaints such as these may indicate an IAQ problem, especially if more than one complaint comes from the same area of the building.

Sick Building Syndrome (SBS) should be suspected when at least 20 percent of a building's occupants complain about acute discomfort for at least 2 weeks and most of their discomfort ends when they leave. Their symptoms may include headache, fatigue, eye irritation, memory loss, and respiratory irritation.

Exposure to some indoor contaminants can cause people to become ill and remain so long after they leave the building. Such illnesses and infirmities, known as Building-Related Illness (BRI), are characterized by clinical symptoms that require extended recovery times. BRI is confirmed when an indoor contaminant is positively identified; correction usually requires removal of that contaminant. Examples of BRI include hypersensitivity pneumonitis (HP), legionnaire's disease, and some cancers.

A survey of the building occupants is a good way to determine what ill effects the occupants may be experiencing. The survey should take the form of a simple questionnaire that asks a series of questions to determine if occupants feel any ill effects related to their indoor environment. An IAQ survey might include the following questions:

1. Where do you spend most of your time in the building?
   Where are you when you experience symptoms (or discomfort)?
2. What kind of symptoms or discomfort are you experiencing?
3. When did your symptoms start?

Table 1
Key IAP Indicators

What To Measure	Measuring Tools	Who Should Measure	When and Where To Measure	Why
Occupant Complaints	**1) Survey of building occupants** 2) Individual complaints	Staff	Use a survey to determine occupant complaints. Compile a list of any individual complaints.	Occupant complaints are usually the first indication of IAP, and are useful for determining the location and frequency of the problem.
Ventilation (CO_2)	**1) Standard detection tubes** 2) Nondispersive infrared (NDIR) direct-reading analyzer 3) Architectural plans/design load specifications	Staff	Carbon dioxide should be measured in the work area, at air outlets, at the exhaust opening, and at the outdoor air intake. The level of CO_2 is highest in the afternoon, and should be measured then. The design load specifications give the amount of fresh air at the outdoor air intake.	High levels of CO_2 (greater than 1000 ppm) indicate that there is little ventilation, and that may mean other more dangerous compounds are trapped in the building as well.
Relative Air Velocity and Movement	**1) Chemical smoke tubes** 2) Architectural and mechanical plans 3) Testing and balancing reports for the HVAC system 4) Hot-wire anemometer 5) Flow hood 6) Neutral density balloons 7) Soap bubbles 8) E.C. detector with tracer gas	Staff Professional	Air velocity is best measured at each workstation (local) rather than an averaged or overall velocity. If the smoke tubes are released in the middle of the room, they indicate the circulation patterns in the room. If released in front of grilles or diffusers, they indicate the flow of the air in the HVAC system (strong, sluggish, etc.)	The rate and flow of air, especially in local areas (not generalized averages), may indicate a problem in air distribution patterns, a deficiency in the HVAC system, or some other factor that could aggravate an indoor air quality problem. It also indicates patterns that pollution could spread in. There are correlations between levels of contaminants and the rate of air flow at the same location.
Mean Radiant Temperature	**1) Global thermometer** 2) Thermometer 3) Thermohygrometer 4) Thermographs 5) Thermistor 6) Thermocouple/data collector 7) Fast-reacting electric thermometers	Staff	Temperature measurements should be taken at all problem locations and at all sites where pollutants are tested for (for comparison between tests taken at different locations). Thermometers can be tested next to the room thermostat to confirm the calibration. Thermographs should be measured over a period of a week.	High temperature may aggravate indoor air contaminants in the building. Low temperature level reduces off-gassing of contaminants from building materials and reduces possible microbial growth. Higher temperature causes formaldehyde and other VOCs to off-gas in higher amounts. Check for formaldehyde, VOCs, and biological contaminants when temperature is high.
Relative Humidity	**1) Sling psychrometer** 2) Thermohygrometer	Staff	Relative humidity measurements should be taken at all problem locations, and at all sites where pollutants are tested for (for comparison).	Higher levels of relative humidity may indicate that the room is uncomfortable. High humidity also supports growth of pathogenic or allergenic organisms. Check for formaldehyde and biological contaminants when humidity levels are high.
Odor	**1) Sense of smell** (if odor is strong enough to irritate employees, it is an IAQ air problem) 2) Portable odor monitor	Occupants and staff	When odor becomes apparent, measure at location of odor.	Indicates possible indoor air quality problems (e.g., poor ventilation, mold, formaldehyde, combustion byproducts, etc). Check for biological contaminants when there is any odor of mold (damp or musty). Check for formaldehyde or other VOCs when the furniture smells odd, or when other building materials have a chemical smell. Check for ETS or carbon monoxide when the smell of a combustion product is present.

Note: Tools listed in bold type represent the authors' first recommendation, based on effectiveness, cost, and ease of use.

When are they generally worst?
Have you noticed any other events (such as weather events or activities in the b. ilding) that tend to occur around the same time as your symptoms?

4. When are your symptoms relieved?
5. Do you have allergies or other health problems that may make you particularly sensitive to environmental problems?
6. Do you wear contact lenses?
7. Do you have any complaints about building conditions?

The occupants can also keep track of any ill effects in a health diary, noting the time and date of the occurrence, the location in the building, the symptoms, and their severity and duration. An accurate diary of complaints can help pin down the cause of the health problem.

Ventilation

Ventilation is a measure of the amount of fresh outdoor air that enters a building. The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) suggest a standard ventilation rate of 20 cubic feet per minute (cfm) per person in office space and conference rooms, 15 cfm per person in reception areas, and 60 cfm per person in smoking lounges.* Low ventilation rates (not enough outside air) are common in buildings that are sealed tightly to reduce energy costs.

The amount of ventilation in a building can be determined by measuring the level of carbon dioxide (CO_2). Carbon dioxide levels higher than 1000 parts per million (ppm) indicate that too much carbon dioxide is being trapped within the building. This is not a direct threat to health, but it is a strong indication of inadequate ventilation. Other contaminants may be trapped in the building as well instead of being exhausted to the outside and diluted with outside air.

Carbon dioxide can be measured using detection tubes with a pump (hand-powered or electric). Attach the detection tube to the hand pump, pump air through once, and the tube will register the amount of CO_2 in that air sample. Maintenance personnel should use these tools to measure carbon dioxide in the work area, at air outlets, between rooms, between air handling zones, at the building exhaust outlet, and at the outdoor air intake. Measurements should be taken away from all direct sources (i.e., 2 ft [0.6 m] away from the investigator or other occupants). The best time to measure for carbon dioxide in the workplace is in the afternoon, because occupants have been in the building long enough to raise the carbon dioxide level to its daily maximum. This principal applies only on normal working days; holidays and weekends will not follow this pattern. Another tool for measuring carbon dioxide is the nondispersive infrared (NDIR) direct-reading analyzer. This device runs on a rechargeable battery and can either monitor carbon dioxide continuously or make a one-time measurement. The gauge on the meter always shows the current carbon dioxide level.

Ventilation rates can be verified by checking architectural plans or the design load specifications. Cross-referencing design specifications with actual ventilation rates may reveal that an increase in ventilation is required to fulfill the designer's intentions.

*20 cfm = 9.44 l/sec; 15 cfm = 7.08 l/sec; 60 cfm = 28.32 l/sec.

Relative Air Velocity and Movement

The rate and flow of air may indicate a problem in air distribution patterns, a deficiency in the heating, ventilating, and air conditioning (HVAC) system, or some other factor that could indicate an IAQ problem. Measurements of the overall air velocity can be useful as a first step, but more specific measurements in local areas are needed to determine the severity of any air flow problem and its effect on the air quality in that area. Air velocity and movement may indicate patterns in which IAQ can spread, or areas with higher concentrations of contaminants due to poor air circulation.

The building maintenance staff should consult the architectural and mechanical plans of the building before starting to measure air flow. The plans may indicate the areas that will have the worst problems. Testing and balancing reports for the HVAC system are also useful in determining parts of the system that may contribute to IAQ problems.

After this initial investigation, chemical smoke tubes can be used to visually check the flow of air in the room. These are glass tubes filled with an aerosol that becomes visible as moisture condenses on its molecules, producing a white "smoke" that is thermally neutral, easily visible, and can be used to follow local flows at low velocity. They are simple to use, so no trained professionals are necessary. Measurements taken with the smoke tubes in the middle of the room will indicate general air circulation patterns, while those taken in front of air grilles or diffusers will indicate the air velocity (fast, sluggish, etc.). Chemical smoke tubes are especially useful for measuring flow through cracks and gaps at windows and doorways. Measurements should be taken at both the top and bottom of doorways because air flow can differ between the two levels. Maintenance personnel need to keep in mind that ventilation patterns depend on a variety of factors such as HVAC operating conditions, the opening or closing of windows, etc.

Two other common tools for measuring air velocity are the hot-wire anemometer, which is good for measuring low flow rates, and the flow hood, which measures air flow rates from grilles and diffusers.

There are other methods of testing air flow, but most of them are not as simple, straightforward, or effective as chemical smoke tubes. Neutral density balloons can get stuck between objects, they break easily, and are affected by static electricity. Soap bubbles are an inexpensive tool, but their movements may be misleading; they start out warmer than the room air, and when they cool they may fall even though there is no downward current moving them. Tracer gas methods are more expensive and often interfere with normal operation of the building during testing.

Mean Radiant Temperature

Temperature may aggravate an IAP problem. The higher the temperature, the faster formaldehyde and other volatile organic compounds (VOCs) will off-gas (escape) from furniture and building materials. High temperatures also stimulate the growth of biological contaminants such as molds and fungi. But primarily, temperature is measured to locate excessively warm or cool areas where IAQ problems could concentrate. A room that has a temperature problem could easily have a problem with air contaminants as well.

Maintenance personnel can take temperature measurements with a globe thermometer. This is a thermometer inside a globe of black paper or other material used to read an average of the temperatures from all directions. The black globe absorbs heat from all sources whereas a simple bulb thermometer reads different temperatures depending on whether the thermometer is held upright, sideways, or upside-down.

The calibration of the globe thermometer must first be tested next to the room's thermostat for comparison. Temperature should be checked in all areas where air velocity and humidity are tested. The temperature should also be noted at all previously identified problem locations.

Other tools for measuring temperature include the standard bulb thermometer; the thermohygrometer, which measures both temperature and humidity, but is more expensive; the thermistor; the thermocouple; and the fast-reacting electronic thermometer, which can be used to take readings in many rooms simultaneously. The globe thermometer, however, takes the most accurate readings and is quite cost-effective.

Relative Humidity

Relative humidity is measured to locate areas of high or low humidity that may also have IAQ problems. Increases in humidity prompt the off-gassing of formaldehyde and the growth of biological contaminants, just as increases in temperature do. Like temperature, humidity can also indicate the areas where IAP may concentrate.

Maintenance personnel can measure relative humidity with a sling psychrometer. This is a simple piece of equipment incorporating both a dry bulb and a wet bulb thermometer. Together with a psychrometric chart, the sling psychrometer measures the relative humidity of a space. The bulb of the wet bulb thermometer is wrapped in a piece of cloth that should be wetted with distilled water before measuring. Relative humidity should be measured in the same locations where temperature is measured—at all contaminant test sites and any suspected problem areas.

Moisture spots, water damage, and condensation may all indicate excessively high relative humidity and therefore, excessive microbiological growth. Humid and water-damaged materials and furnishings should be cleaned or replaced immediately.

Another tool that measures relative humidity is the thermohygrometer, discussed previously, which measures both temperature and humidity.

Odor

Odor generally indicates that there is some air contamination that is not being adequately ventilated. Odor may indicate a number of IAQ problems, such as molds or other biological contaminants, formaldehyde, or combustion byproducts.

Odor is measured subjectively by maintenance personnel and occupants using the sense of smell. A damp or musty smell may indicate mold or another biological contaminant. When the furniture smells odd, or building materials emit a chemical odor, formaldehyde or other VOCs may be the problem. Environmental tobacco smoke (ETS) is indicated by its commonly recognizable odor. Carbon monoxide, nitrous oxide, sulfur oxide, and particulates are all possible in spaces where the smell of a combustion byproduct, such as car exhaust, is present.

Odor can also be measured objectively with an odor monitor. This is a device that runs on batteries and continuously monitors odor levels.

Measuring Indoor Air Contaminants

When an IAQ problem is detected through the measurement of one of the indicators previously discussed, the specific cause of the problem must be determined. Sometimes the indicator itself may identify the contaminant causing the problem. For example, when an odor of auto exhaust is present, high levels of carbon monoxide are possible. However, when the indicators point to several possible causes, all appropriate contaminants should be investigated. Table 2 lists the eight most common indoor air contaminants identified by the authors in a literature search. Testing for these eight contaminants will uncover the cause of most IAQ problems. The bold listings in the "Measuring Tools" column of Table 2 represent the authors' recommended sensing technology for the given contaminant, based on effectiveness and cost. The Appendix comprises a glossary of all sensing technologies listed in Table 2 (and elsewhere in this report). The contaminants are discussed below.

Formaldehyde

Formaldehyde is used in various building materials and furnishings, especially insulation, particle board, waferboard, and furniture. Formaldehyde off-gasses from these materials, and can collect to harmful concentrations in underventilated spaces. The U.S. Environmental Protection Agency (USEPA) action level for formaldehyde—the maximum level allowable before mitigation is required—is 0.1 ppm.[1] High temperature and humidity stimulate the rate of off-gassing. A high ventilation rate will dilute the contaminant, reducing its harmfulness. However, when the furniture or building materials containing formaldehyde are new, they will off-gas in large amounts regardless of temperature and humidity, and high ventilation rates actually stimulate off-gassing until most of the formaldehyde has escaped.

Formaldehyde can cause dry skin and irritate the mucous membranes. At higher concentrations it can cause respiratory disease, asthma, and—eventually—cancer. When the odor of formaldehyde is present, it has already accumulated to a dangerous level. To measure for it before it produces an odor, the most common methods are impingers or sorbent tubes. The impinger method is described in the NIOSH Standard 3500,[2] and the sorbent tube method is described in OSHA Standard 52.[3] Both of these methods should be done by professional air quality investigators. Two more expensive methods of measuring formaldehyde are an air pump with formaldehyde-trapping filters and an infrared direct-reading meter.

Volatile Organic Compounds (VOCs)

Formaldehyde is one widely used member of this large group of contaminants. VOCs are used in many building materials and cleaning products, and will off-gas into the indoor air. High temperatures stimulate off-gassing.

VOCs irritate the eyes, nose, and throat; may cause headaches, loss of coordination, nausea; and can damage the liver, kidneys, and central nervous system. Some VOCs are suspected or known to cause

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[1] *The Inside Story—A Guide to Indoor Air Quality* (U.S. Environmental Protection Agency [USEPA], Consumer Product Safety Commission, September 1988).

[2] Peter M. Eller, Ed., *NIOSH Manual of Analytical Methods*, National Institute of Occupational Safety and Health (NIOSH) Standard 3500, 3d ed., DHHS/NIOSH #84-100 (NIOSH, 15 May 1989).

[3] Occupational Safety and Health Administration (OSHA) Standard 52, 2d ed., *OSHA Analytical Methods Manual, Part I—Organic Substances*, Vol 2 (U.S. Department of Labor, January 1990), pp 52-1 – 52-38.

Table 2
Most Common Indoor Air Contaminants

What To Measure	Measuring Tools	Who Should Measure	When and Where To Measure	Why
Formaldehyde	1) **Impinger** 2) Sorbent tubes 3) Air pumps with tubes for formaldehyde 4) Infrared direct-reading analyzer	Professionals (Action Level: 0.1 ppm)	Formaldehyde is sampled when building materials or furniture are sources of odor. Increases in temperature and humidity may also indicate a formaldehyde problem since the formaldehyde will off-gas faster in higher temperatures or high humidity. Large variations in levels can occur during short periods of time (hours) due to changes in the temperature or humidity.	Formaldehyde can cause irritation of the mucous membranes and dry skin. At higher levels it may cause respiratory disease, asthma, and eventually cancer.
Volatile Organic Compounds (VOCs)	1) **Direct-reading meter with PID** 2) Canister methods or solid-sorbent methods 3) Activated charcoal sampling tubes	Staff Professionals	VOCs are sampled when there is an odor present in the building or when irritative components are suspected to be present, as they are often the cause. VOCs off-gas faster with high temperatures.	VOCs may cause eye, nose, and throat irritation; headaches, loss of coordination, nausea; damage to liver, kidney, and central nervous system.
Respirable Suspended Particles (RSP)	1) **Air pumps with filters for RSP** 2) Direct reading meter (using scattered light) 3) Piezoelectric microbalance	Professionals	RSP may be a problem due to construction, smoking indoors, or intake of polluted outdoor air. Horizontal surfaces are indicators of visible levels of dust. For suspended particles, the air must be checked.	High RSP levels indicate poor cleaning, tobacco smoke, handling of paper, or "poor" outside air. RSP will also aggravate the problem of radon or biological contaminants.
Biological Contaminants	1) **Visual checks of humidifiers and AC units** for excess moisture, and presence of moisture spots on building materials 2) Microbiological sampling device	Staff Staff (and professional lab to analyze samples)	Moisture spots, flood damaged furniture or building materials, or poorly maintained humidifiers, dehumidifiers, and AC units indicate risk of biological contaminants. High relative humidity will also increase the growth rate of biological contaminants.	Biological contaminants collect on dust particles and irritate the lungs, or cause allergic reactions or diseases such as humidifier fever, asthma, or influenza. They can also irritate the mucous membranes or cause shortness of breath or lethargy.
Asbestos	1) **Asbestos sampling kit, protective wear, and HEPA filter vacuum** 2) Air sampler with filter for asbestos	Staff (trained in sampling and repair by asbestos consultants, EPA) and qualified lab (to analyze samples)	Asbestos is sampled when ACM is suspected to be present, especially if it is damaged. All possible ACM should be sampled, including pipe insulation, sprayed-on surfaces on wall, ceilings, or structural steel, and floor tiles.	Asbestos fibers, when released from building materials, irritate the lungs and can cause asbestosis, mesothelioma, lung cancer, and gastrointestinal cancers. It increases the risk of cancer in smokers by 50 times.
Carbon Monoxide	1) **Odor of auto exhaust, combustion** 2) Dosimeter tube 3) Infrared direct-reading analyzer	Staff Professionals	Sample for carbon monoxide when the odor of vehicle exhaust or other combustion product is present in the building.	Carbon monoxide is toxic and can cause headaches at low levels, and asphyxiation at higher levels.
Radon	1) **Alpha track detectors** that are exposed for 1 month or longer 2) Charcoal canisters (exposed for 2 to 7 days)	Staff (and professional lab to analyze samples) (Action Level: 4 pCi/l)	Radon should be measured over long term (more than 72 hours) because the short-term measurements are not as precise.	Radon can cause lung cancer. When the particulate level in the air is high, radon is additionally dangerous because it adheres to the respirable particles.
Environmental Tobacco Smoke (ETS)	1) **Sense of smell** 2) Sampling for airborne nicotine.	Employees or staff	Any odor of tobacco smoke indicates need for measurements of ETS.	The irritation of tobacco smoke can slow down employees. ETS has also been known to cause lung cancer and to contribute to heart disease. ETS also aggravates exposure to radon by five times.

Note: Tools listed in bold type represent the authors' first recommendation based on effectiveness, cost, and ease of use.

cancer in humans. When there is an odor present in the building, or when the presence of irritative components is suspected, VOCs should be checked.

VOCs may be measured using a direct-reading meter with a photoionization detector (PID). This instrument measures the total organic gas concentration in the air. It uses a battery-operated air pump to force the air past the PID, and must be calibrated (using calibration gasses) for accuracy. The meter reports the level of VOCs in that air sample.

Two other methods for measuring VOCs are canisters and sorbent tubes. Canisters collect VOCs onto a sorbent material passively, but must be placed for a longer period of time to collect an adequate sample. These are difficult to measure because there is not a controlled flow of air through the sorbent material. Solid sorbent tubes measure VOCs by use of a hand-powered or (more common) electric pump, which draws air through the tube containing the sorbent (usually activated carbon or silica gel). The tube must be sent to a laboratory for analysis.

Respirable Suspended Particles (RSP)

Particles in the air that are small enough to be breathed in and trapped in the lining of the lungs are called RSP. RSP may become a problem due to the intake of polluted outside air, nearby construction or remodeling, poor cleaning, excessive handling of paper, or ETS. Each of these factors will increase the level of RSP in the air.

RSP aggravates dust-related allergies. It also aggravates the problem of radon or biological contaminants. Radon daughters—the radioactive decay products of radon gas—are most dangerous when they attach to a dust particle and become embedded in the lungs. RSP provides the dust particles that make radon a substantial health threat. Dust particles can also carry biological contaminants or strong allergens, such as the fecal pellets of dust mites.

Horizontal surfaces should be checked to see if there is a visible deposit of dust that might indicate an RSP problem. RSP can also be measured with a direct-reading meter using scattered light. This procedure should be done by a professional air quality investigator rather than the maintenance staff. Two other methods used to check for RSP are an air pump with filters for trapping RSP and a piezoelectric microbalance. These methods are more expensive than visual inspection, but they can quantify RSP levels more precisely.

Biological Contaminants

Biological contaminants include microbes, molds, plant spores, and dust mites. They collect on dust particles and irritate the lungs, and cause diseases such as "humidifier fever," asthma, or influenza. They can also irritate the mucous membranes and cause shortness of breath or lethargy.

Moisture spots, flood damaged furniture or building materials, or poorly maintained humidifiers, dehumidifiers, and air conditioning (AC) units can promote the growth of biological contaminants as does an excessively high level of relative humidity. When high humidity is combined with the presence of materials high in cellulose content, even with low nitrogen content (fiberboard, dust, lint, skin particles, and dander), the growth of biological contaminants increases.[4]

Maintenance personnel should do visual checks of humidifiers and AC units for excess moisture, and check for the presence of moisture spots on building materials. A microbiological sampling device can determine the presence of gross biological contamination. This device requires a sterile petri dish prepared with agar—a nutrient for microbes—for each sample taken. The dish is put into the sampler that is connected to an air pump. After the sample is collected, the petri dish is removed and sent to a microbiology laboratory for analysis. The laboratory will incubate the petri dishes and count the number of colony-forming units (CFUs) in the sample.

Asbestos

Asbestos fibers are very small. When inhaled they will irritate the lungs and can cause asbestosis, mesothelioma, lung cancer, and gastrointestinal cancers. For smokers, asbestos fibers can increase the risk of cancer by 50 times. Asbestos is not dangerous if it is sealed in building materials where it cannot be freed into the air. However, all suspect building materials should be checked for asbestos content, and then monitored to assure that no asbestos-containing material (ACM) is damaged without immediate action taken to contain it.

Because ACM was in the past used in the construction of many buildings—especially those built between 1930 and 1978—asbestos is considered to be a very widespread problem. And because the potential health consequences of asbestos exposure are so serious, a detailed investigation procedure for detecting and identifying ACM is presented here. A complete audiovisual presentation of this procedure is available in the videotape *Asbestos Management Series*, VID021 (USACERL, 1989). The procedure follows:

Determine extent of problem. Contact USEPA first and get current technical documents. Also get current OSHA and Army regulations.

Survey building. USEPA has a listing of consultants for asbestos management. A consultant can advise where to look for asbestos, and can train the staff to take samples. During the survey, the staff should:

1. Identify ACM Locations. Look for both friable (crumbly) and nonfriable ACM. Review building records (architectural and mechanical plans) to find noted locations of asbestos. Four common types of ACM are:

   - Preformed wrap (3 in. [7.62 cm] half-cylinder sections taped or banded around a pipe)

   - Corrugated paper (or "air cell") (gray or white cardboard used as pipe covering)

[4] ASHRAE Standard 62-1989, *Ventilation for Acceptable Indoor Air Quality* (American Society of Heating, Refrigerating, and Air-Conditioning Engineers [ASHRAE], 1989).

• Boiler insulation (brick or block containing asbestos, or asbestos blankets)

• Tank insulation (loose asbestos fill held in place by light gauge mesh covered in sheet metal).

Check plaster, fiber textiles, vinyl floor tiles, thermal or acoustical insulation, sprayed-on surfaces on walls, ceilings, or structural steel, and pipe insulation.

2. Assess Potential Harm. Note whether ACM is damaged or intact. Determine whether the ACM is accessible by employees or maintenance personnel. Note usual use of space (to determine whether ACM may become damaged easily). Note whether ACM is friable (crushable using only hand pressure) or nonfriable.

3. Record Findings. Make notes on the building plans. Keep a log book of all possible asbestos locations. Record location and estimated surface area of any damaged ACMs. Note proximity of ACM to return ducts. Determine if asbestos may have accumulated in return air plenums.

<u>Alert Building Personnel to the Problem</u>. Show personnel location of ACM. Tell them to report all damage, including crumbling, scratches, and even water spots. Train all workers in ACM area in repair and removal, or have them notify personnel who are trained instead of disturbing the area themselves. It is dangerous to brush or sweep the material, such as plaster that falls out of the ceiling onto a desk or the floor, because fibers can easily be swept into the air. ACM should be wet down first, then vacuumed using a high-efficiency particulate air (HEPA) filter vacuum cleaner. This vacuum cleaner can catch the very small asbestos fibers that a regular vacuum would return to the air. Do not disturb ACM without wearing a protective respirator. Note only workers authorized by a medical professional can wear a respirator. Respirators should be fitted specifically for the individual wearer.

<u>Assemble a Sampling Kit</u>. It should contain the following:

1. Plastic squeeze bottle with "amended water" (containing a wetting agent)
2. Plastic containers with snap caps or other leak proof stopper suitable for mailing
3. Tweezers or wooden sticks to take samples where material cannot be penetrated easily
4. Container labels with content information, and warning labels for shipping ACM
5. Sample log forms
6. Paper towels
7. Tape for sealing containers
8. Indelible marker for marking labels
9. Disposable plastic gloves
10. Plastic disposal bags marked for containing ACM

11. Protective eyewear and headgear

12. Disposable coveralls (sacks suits)

13. Dropcloth

14. OSHA-approved respirators

15. Ladder

16. HEPA filter vacuum

17. Piece of electrical conduit with fine beveled edge for scraping and holding samples

18. Latex paint or nonasbestos mastic to seal sample areas

19. Fluorescent spray paint to mark sample area.

Collect Samples. First plan a sampling method. Sample similar areas ("homogenous sampling areas"), where ACM is similar in texture and appearance and has identical histories. Take at least three samples from each homogenous sampling area. In addition, take one quality assurance sample per building, or one for every 20 regular samples, to be sent to a second laboratory that uses an identical analysis method as the lab doing the ACM analysis. Also take one settled-dust sample in each area. To collect the sample, use the following procedure:

1. Spray area wet thoroughly

2. Penetrate with sample container, twisting it firmly into the material. If the container can not penetrate the material, use the tweezers or sharpened conduit edge to cut into the material slightly. If the ACM is a powdery cement texture, use the edge of the container to scrape the material into the container

3. Wipe the edge of the container with a damp cloth or paper towel

4. Label the containers with (a) sample identification number, (b) date sample was taken, and (c) name of the person who took the sample. Accurately record each sample on a log form.

5. Seal the container with tape

6. Seal the area where the sample was taken with the latex paint or nonasbestos mastic, and spray the fluorescent paint over it to mark it

7. Wipe tweezers with damp paper towel

8. Dispose of paper towels, wooden sticks, drop cloth (spray wet and fold up first), and any other disposables into a plastic disposal bag marked for containing asbestos. Wet mop the floor if no drop cloth was used, then thoroughly clean the mop with soap.

Have Samples Analyzed. Send samples to a USEPA-qualified lab for analysis. For each sample, be sure to include identification number, building address, date and time sample was taken, location of sample, type of material sampled and physical condition of material, name of the person who took the sample, and any additional remarks. It may be most convenient to send a copy of the log forms filled out during sampling. If the lab tests should find asbestos present, consult the log books to see which areas of ACM were damaged or could easily be damaged. That material will have to be removed or encapsulated by specially trained professionals.

Carbon Monoxide

Carbon monoxide itself is an odorless gas, but it is often accompanied by exhaust fumes or combustion byproducts that do have an odor. Carbon monoxide is toxic. At lower levels it can cause headaches and eye irritation. At high levels it can cause death by suffocation.

Maintenance personnel can check for the odor of re-entrained building exhaust fumes, vehicle exhaust, ETS, or other combustion, since these smells usually accompany carbon monoxide. Carbon monoxide can be measured with a dosimeter tube, which fits into a hand-held scale and registers a direct reading of the carbon monoxide. An infrared direct-reading meter can also measure carbon monoxide, but it is more expensive.

Radon

Radon is a radioactive gas produced by the radioactive decay of the element radium. It accumulates in the earth and is pulled into buildings through cracks in the foundation and other entry points. Radon itself decays into radon daughters which are dangerous when they bond with dust particles that allow them to embed in the lining of the lungs when inhaled. Radon in the lungs may cause lung cancer. The action level for radon is 4 picoCuries per liter (pCi/l).

Maintenance personnel should check for radon using alpha track detectors. These are placed on the lowest level of a building and exposed for 1 month or longer. The exposed plastic film must be sent to a laboratory for counting. There are also short-term radon detectors available such as charcoal canisters that require exposure for only 2 to 7 days. These are used for screening purposes to find high levels (greater than 20 pCi/l). The canisters must then be sent to a laboratory for analysis. However, some States recommend that residents use only the alpha track monitors because the longer sampling time offers more precise measure of radon levels. Both kinds of detectors are placed when the building is closed to outside ventilation, usually during the winter when windows are less likely to be opened.

Environmental Tobacco Smoke (ETS)

The presence of ETS can reduce employee productivity by causing eye or lung irritation. ETS is also known to cause lung cancer and contribute to heart disease. ETS aggravates the danger of exposure to radon by a factor of 5 because it contains respirable particles to which radon daughters can attach and embed in the lungs.

The most direct way to check the ETS level is to have maintenance personnel and occupants smell the air. If the level is high enough to smell, it should be considered an IAQ problem. A professional air quality inspector can provide a more quantitative report on the presence of ETS by sampling and analyzing the air for airborne nicotine.

3 CONCLUSION

Indoor air quality problems can have a serious effect on the comfort, health, and productivity of building occupants. Effects may include annoyance, physical irritation, illness, permanent incapacitation—even death. It is obvious that any of these effects can cause employee absenteeism and lower productivity. IAP costs both employees and employer (building occupants and owners) time and money.

IAP must initially be addressed by building maintenance personnel, who can frequently investigate and control it before it causes any serious problems. Environmental sensor technology enables maintenance personnel to detect an IAQ problem, identify its cause, and address the source or control the effects. For some contaminants, however, the best "sensor" currently available is the human nose.

Most environmental sensors discussed in this report can be operated by maintenance personnel with little training. A preventive maintenance routine can be set up to monitor the building for IAP indicators and contaminants. Such maintenance should include simple visual checks for dust, mold, etc.; chemical sampling for less obvious contaminants; and an overall awareness of the facility that will allow the maintenance staff to identify and address problems before they become serious. For problems beyond the expertise of maintenance personnel, specially trained air quality professionals should be consulted.

Not all of the most common contaminants have been fully researched yet, and environmental sensors are not always the best possible way for maintenance personnel to monitor IAQ. Further research and development should be conducted to simplify environmental sensors so all testing for the most common contaminants can be done by a building staff with a minimum of special training. Clear documentation on how to detect and identify IAP, such as the USACERL videotape on investigating and sampling asbestos, would be helpful toward this end. Investigation into the use of biological sensors, such as plants or animals that can react to IAP before it affects humans, might make it possible to continuously monitor the indoor environment simply by placing a particular plant in a potential trouble spot. This type of "early warning system" would be very useful since some pollutants are already quite hazardous by the time they have accumulated to visible or smellable levels.

The environmental sensor technology that is currently available is effective in testing for some of the most common and troublesome contaminants, and much of it can be operated without specialized training or skill. Research to improve this area of technology should focus on expanding it to cover all known threats to IAQ, and making it simple to operate and cost effective.

APPENDIX: Environmental Sensor Technologies and Sampling Devices

This appendix lists the most common technologies for detecting and identifying indoor air contaminants. The indicators or contaminants for which the technologies are used are indicated in square brackets.

Activated charcoal sampling tube [VOCs]: Used in the solid-sorbent method. The activated charcoal is the sorbent material.

Air pump [formaldehyde, RSP, asbestos]: Electric motor draws air through a filter or other measuring device to collect a sample of a contaminant.

Alpha track detectors [radon]: Used to collect an accurate long-term measurement of radon. Plastic film that collects sample must be sent to laboratory for analysis.

Asbestos sampling kit [asbestos]: An assembly of tools for collecting samples of possible ACM to be sent to a laboratory for analysis.

Canister method [VOCs]: A method that uses a canister containing a sorbent material to passively collect a sample of VOCs.

Charcoal canister [radon]: A short-term measurement of high levels of radon. Must be sent to a laboratory for analysis.

Chemical smoke tube [air movement]: Used to visually trace air movement by use of a special neutral density smoke that is not produced by combustion.

CO_2 detection tube [carbon dioxide]: Used with a hand or electric air pump for one-time direct-reading measurement of CO_2.

Direct-reading meter [VOCs, RSP]: Any meter that can be read directly and does not need to be sent to a laboratory for interpretation.

Dosimeter tube [CO]: Glass tube that fits into a hand-held scale and registers a direct reading of the level of CO after 15 minutes of exposure.

E.C. detector with tracer gas [air movement]: Detector records the movements of the tracer gas, which follow the air movement pattern.

Fast reacting electric thermometers [temperature]: Used for taking temperature measurements in more than one location simultaneously.

Flow hood [air velocity]: Attached to an HVAC system supply diffuser to measure air velocity at that diffuser.

Globe thermometer [temperature]: Incorporates a black paper globe that measures an average of the radiant temperature from all directions.

Hot-wire anemometer [air velocity]: Measures air velocity as air passes over an electrically heated wire.

Impinger [formaldehyde]: Measures formaldehyde level by drawing sample of air through a liquid.

Infrared direct-reading meter [CO_2, formaldehyde, VOCs, CO]: Meter registers the level of a substance by measuring its infrared absorption band.

Microbiological sampling device [biological contaminants]: Collects a sample of biological contaminants on a petri dish of agar. Must be sent to a laboratory to count the level of colony-forming units (CFUs).

Neutral density balloon [air movement]: A balloon containing a gas, which combined with the weight of the balloon material, is equal to the weight of air. It floats in a room's air, revealing air movements.

Nondispersive infrared detectors (NDIR) [carbon dioxide, formaldehyde, VOCs, CO]: Measures the infrared absorption band of a particular gas continuously.

Piezoelectric microbalance [RSP]: Measures RSP by weight.

Portable odor monitor [odor]: Measures any odor is detectable by humans and displays level.

Sling psychrometer [humidity]: Measuring device with a dry bulb and a wet bulb (wet with distilled water) which is whirled quickly in a circular motion for 30 seconds to measure both humidity and temperature.

Soap bubbles [air movement]: Commercial soap bubbles which float in a room's air, revealing air movements.

Solid-sorbent method [VOCs]: A method that uses a sorbent (absorbing material) to collect a sample of VOCs.

Sorbent tubes [formaldehyde]: Glass tube containing a sorbent (usually activated carbon or silica gel) that is used to measure formaldehyde by absorbing a sample from air drawn through the glass tube by a pump. The tube must be sent to a laboratory for analysis.

Thermistor [temperature]: An electrical resistor whose resistance varies with temperature.

Thermocouple [temperature]: A device that registers (through a datalogger) the difference in potential created at a connection of two wires of dissimilar metal.

Thermographs [temperature]: Measures temperature in graph form on a paper roll.

Thermohygrometer [temperature, humidity]: Battery-run device that measures both temperature and humidity .

Thermometer [temperature]: Simplest tool for measuring temperature.

ABBREVIATIONS AND ACRONYMS

AC	air conditioning
AR	Army Regulation
ACM	asbestos containing material
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BRI	Building-Related Illness
CFU	colony-forming unit
CO	carbon monoxide
CO_2	carbon dioxide
ETS	environmental tobacco smoke
HP	hypersensitivity pneumonitis
HVAC	heating, ventilating, and air conditioning
IAP	indoor air pollution
IAQ	indoor air quality
NDIR	nondispersive infrared (gas monitor)
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
pCi/l	picoCuries per liter
PID	photoionization detector
ppm	parts per million
RSP	respirable suspended particles
SBS	Sick Building Syndrome
USACERL	U.S. Army Construction Engineering Research Laboratory
USAEHSC	U.S. Army Engineering and Housing Support Center
USEPA	U.S. Environmental Protection Agency
VOC	volatile organic compound

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